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SEDIMENTOLOGICAL, PETROGRAPHICAL AND MINERALOGICAL SUBSURFACE STUDY OF MUKDADIYA FORMATION, CENTRAL PART OF IRAQ

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ABSTRACT

Sedimentological study of Mukdadiya Formation (Late Miocene – Pliocene) indicates that its sediments were deposited in fluviatile meandering channels system. The sequence of the formation is composed of several fining-upward cycles in which three facies were recognized: The sandstones facies, represents channels deposits, the gravelly sandstones and conglomerates facies, represents a high energy environment reflecting a climatic or tectonic pulses in the source area, and the fine grained sediments facies, represents overbank deposits.

The petrographic study of the sandstones of Mukdadiya Formation indicates that they are immature, mostly poorly sorted and classified as litharenite. They are composed mainly of quartz and sedimentary rock fragments; the predominant type of sedimentary fragments is carbonate. The study of heavy minerals indicates that epidote group is forming the main heavy minerals, followed by amphibole, pyroxene and garnet. The source rocks; based on petrographical and heavy minerals studies are interpreted to be composed essentially of sedimentary followed by igneous and metamorphic rocks.

The study of clay minerals indicates the presence of montmorillonite, chlorite, illite and kaolinite. The origin of most of these minerals is detrital, however, the chlorite is considered to be partly diagenetic.

دراسة رسوبية وبتروغرافية ومعدنية تحت سطحية لتكوين المقدادية في وسط العراق

مزاحم عزيز باصي

المستخلص

الدراسة الرسوبية لتكوين المقدادية (المايوسين المتأخر – البلايوسين) في منطقة الدراسة بينت بان التكوين قد ترسب في بيئة نهرية إلتوائية. إن محور التكوين تتكون من عدة دورات نهرية تتناعم في حبيباتها نحو الأعلى والتي أمكن تميز ثلاث سحنات وهي: سحنة الصخور الرملية التي تمثل ترسبات القنوات، وسحنة الصخور الرملية الحاملة للحصى والمدملكات وتمثل تغيرات مناخية أو تكتونية في منطقة المصدر وسحنة الترسبات الناعمة وتمثل ترسبات عبر الضفة.

بينت الدراسة البتروغرافية للصخور الرملية لتكوين المقدادية بأنها غير ناضجة وأغلبها رديئة الفرز وتصنف "ليث ارينايت" وتتكون بصورة رئيسية من حبيبات الكوارتز وأجزاء من صخور رسوبية. إن النوع السائد للحبيبات ذات الأصل الرسوبي هي الصخور الجيرية. بينت دراسة المعادن الثقيلة بأن مجموعة الأبيدوت هي الرئيسية، تتبعها معادن الأمفيبول والپايروكسين والگارنيت. إن الدراسة البتروغرافية والمعادن الثقيلة استنتجت بأن صخور المصدر تتكون بصورة رئيسية من صخور رسوبية ثم تليها الصخور النارية والمتحولة. بينت دراسة المعادن الطينية وجود معادن المونتموريلونايت والكلورايت والألايت والكاؤلينايت. إن أصل أغلب هذه المعادن هو فتاتي، بينما أصل الكلورايت هو فتاتي جزئياً وتحويري جزئياً.

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INTRODUCTION

Sedimentological, petrographical and mineralogical subsurface studies of Mukdadiya Formation (Late Miocene – Pliocene) were carried out, in three boreholes at Al-Abbasiya area, in the western side of Tigris River, south of Baji City (Fig.1). The formation was previously named as Lower Bakhtiari Formation and was later changed, in Iraq, to Mukdadiya Formation (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Previous work about the formation in the studied area is stratigraphic and carried out by Yacoub *et al*. (1990). However, outside of the studied area, the formation was studied stratigraphically and sedimentologically by many authors among them are Bellen *et al*. (1958); Kukal and Sadalah (1970); Basi (1973); Jassim *et al*. (1984) and Al-Rawi *et al*. (1992). All those authors suggested that the formation is of continental to subcontinental fluviatile environment. Moreover, Al-Addool (1982) indicated that the formation was deposited in braided and meandering channels in northern Iraq.

The Present work aims to shed light on the sedimentology, petrography and mineralogy of the Mukdadiya Formation, from data of three drilled borehole (ABH1, ABH2 and ABH3), because the formation is not exposed in the studied area. This study is a part (Basi and Karim, 1990) of site investigation project carried out by Iraq Geological Survey.

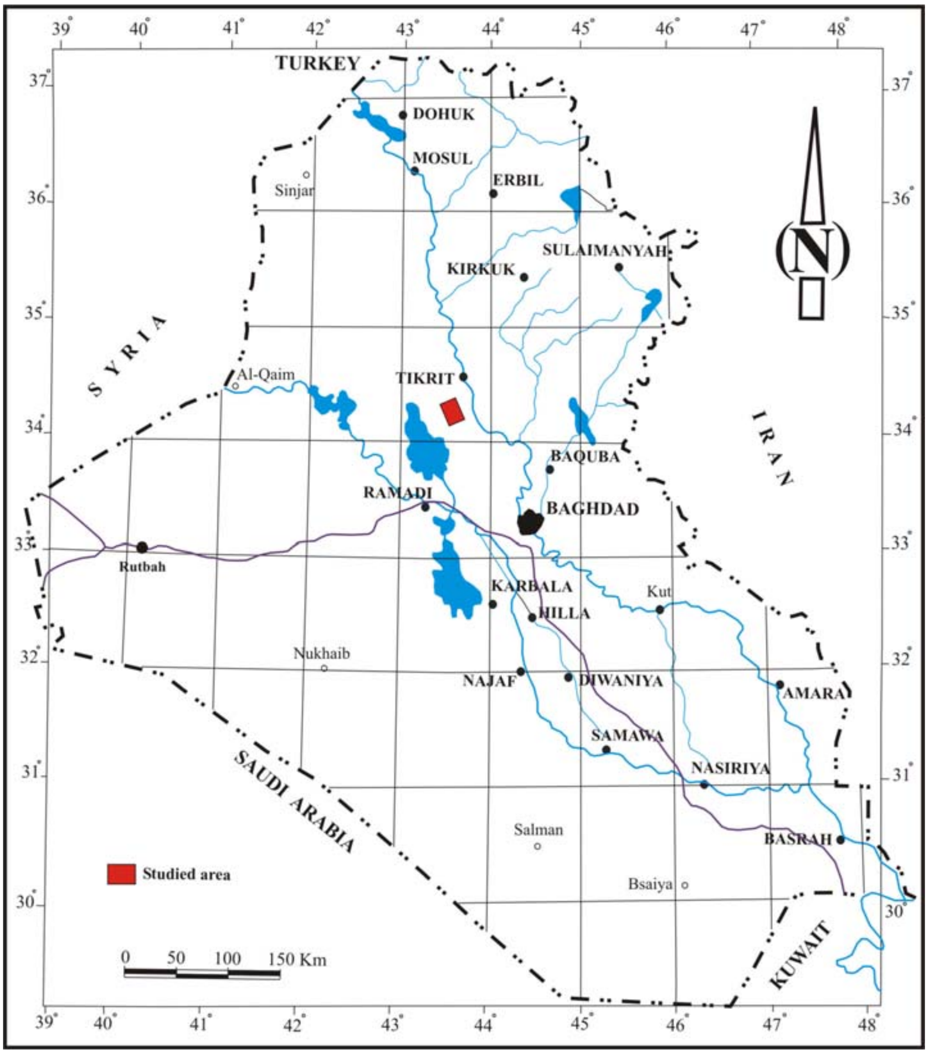

Fig.1: Location map of the studied area

METHOD OF WORK AND MATERIALS

The sediments of Mukdadiya Formation were described in there boreholes emphasizing their lithology, sedimentary structures, nature of contacts, lateral and vertical variations. Twenty eight rock samples were collected for petrographical and heavy minerals studies. The petrographic study was performed by means of polarizing binocular microscope. Alizarin Red S following Friedman's (1959) procedure was used to differentiate the carbonate cementing minerals and carbonate sediments. The heavy minerals study was carried out in the laboratory by separation of heavy sand fraction from the light fraction by Bromoform liquid of specific gravity (2.84 – 2.81). The (60 – 200) micron fraction was studied by polarizing microscope and about 300 grains were counted for each glass slide.

Semiquantitative analysis for clays in 12 samples was performed by weighing of 10 gm from the sample, crushed, and then 25% of acetic acid was added to dissolve the carbonate minerals. The sample was washed carefully from the acid, dried and then weighted to determine the weight of the clay and quartz minerals. Oriented samples were prepared by using Gipson method (Gipson, 1966) and analysed by XRD using Cu and K radiator. The clay minerals identified and calculated by Schultz (1964) and Al-Saadi (1984) methods. The areas under peaks for each individual clay mineral were calculated, and then the percentages of the clay after the subtraction of the quartz percentages were determined. The classification of clay minerals given by Millot (1970) was adopted, because it verifies the approach of this study.

SEDIMENTARY FEATURES OF MUKDADIYA FORMATION

The sediments of Mukdadiya Formation within the studied boreholes represent part of the formation. The formation is underlain by Injana Formation (Late Miocene), and composed mainly of alternation of claystone, mudstone, siltstone and sandstone units. Moreover, few gravelly sandstone and conglomerate units were observed. These sediments form repeated fining-upward cycles and classified into several facies (Fig.2). The following facies were recognized.

- **Sandstone Facies (Facies 1)**

This facies is medium grey to brown in colour and ranges in thickness from about (2 – 12) m. Each facies has erosional scour surfaces at its base and normally cutting sharply and unevenly the underlying mudstone and claystone sediments, occasionally an intraformational conglomerate unit underlies this facies. The sandstone units are mostly medium tough and friable in some parts (loose sand) and the size varies from fine sand to very fine sand. Sedimentary structures include large scale and medium scale cross-bedding and microcross-laminations. Moreover, horizontal bedding and massive bedding are sometimes recognized. This facies is normally overlain by mudstone and claystone units and form part of large scale (> 12 m in thickness) fining-upward sequences in the studied sediments (Fig.2). The occurrence of this sandstone facies as part of fining-upward sequence, being overlain by mudstone and claystone and underlain by intraformational conglomerate, beside the presence of basal scour surfaces and relatively large thickness indicate that this facies is deposited in main channel meandering fluviatile environment; similar to those described by Allen (1964), Al-Haddad *et al*. (1996) and Basi (2007).

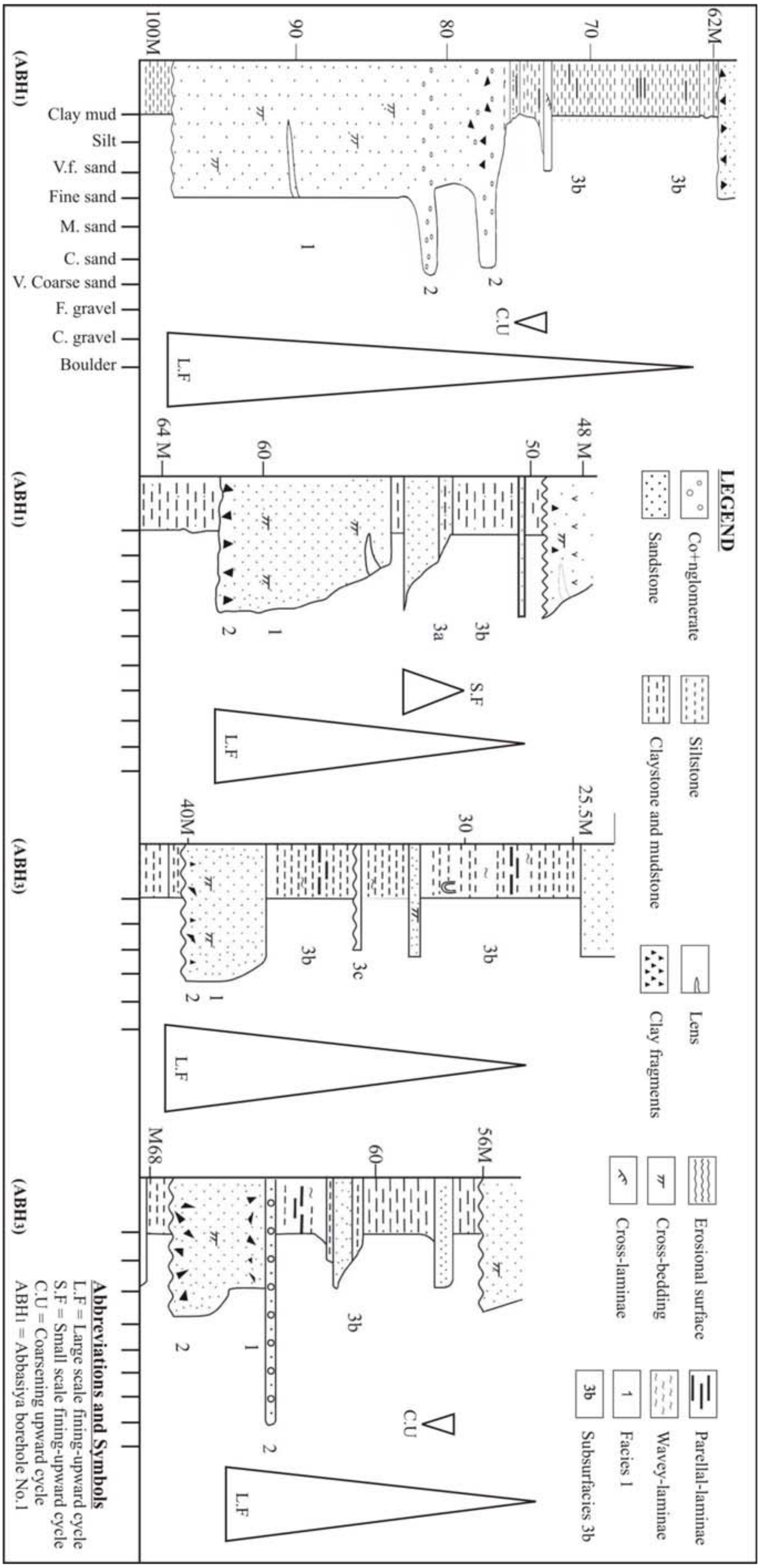

Fig.2: Graphical logs showing representative cycles, facies and subfacies in the Mukdadiya Formation in boreholes ABH1 and ABH3

▪ **Conglomerate and Gravelly Sandstone Facies (Facies 2)**

This facies is either present as a conglomerate units of about 30 cm thick, or as gravelly sandstone units at the base or middle of Facies 1. The gravelly sandstone units are medium grey to brown in colour and are mostly medium tough to tough. Most of the facies are massive, however, horizontal and cross-bedding were observed also. This facies, most probably represents a high energy environment reflecting a climatic change or tectonic pulses in the source area.

▪ **Fine Grained Sediment Facies (Facies 3)**

This facies consists mainly of massive to evenly laminated claystone and mudstone units, with subordinate siltstone and sandstone units. The facies is either overlying or laterally equivalent to Facies 1. Most of the sediments, most probably represent fine suspended – load sediments deposited in overbank alluvial subenvironment. The fine grained sediment facies can be divided into three subfacies (Fig.2): Alternating claystone and/ or Mudstone and siltstone, Mudstone and Claystone and Carbonate Subfacies, they are described hereinafter.

– **Alternated Claystone and/ or Mudstone and Siltstone Subfacies (Subfacies 3a):** The sediments of this subfacies is composed mainly of alternating of claystone and/ or mudstone and siltstone units. Normally it is not exceeding 1 m in thickness and is overlying the Sandstone Facies (Facies 1). The observed sedimentary structures in the siltstones and sandstone units are parallel and micro-cross laminations, with subordinate wavy laminations (due to colour variation), which are common in the claystones and mudstones. This subfacies is most probably formed by overbank flooding as levee sediments.

– **Mudstone and Claystone Subfacies (Subfacies 3b):** The sediments of this subfacies are grey, light brown to medium brown in colour and consist mainly of massive to evenly laminated claystone and mudstone. However, sandstone and siltstone units sometimes interrupt the sediments of this subfacies. The subfacies, usually occupies the top of each large scales fining-upward cycle. From the aforementioned features, most probably the sediments of this subfacies were deposited under flood plain condition. Small scale fining-upward and coarsening-upward cycles were observed within these sediments also. The cycles are considered as small scale, because the sandstones at the base of the fining-upward, and at the top of coarsening- upward cycles are not exceeding 1 m in thickness; as compared to the large scale fining-upward cycles. Moreover, they are randomly distributed and interrupt the fine grained sediments of the large scale fining-upward cycle. The small scale fining-upward cycles might be formed by lateral migration of the crevasse splay(s) in the flood plain sediments, whereas the small scale coarsening-upward cycles might represent a progradation of permanent crevasse splay(s) into flood basin (shallow lakes). Sandstone units of non-vertical variations in grain size, are mostly of sharp bases and range in thickness from (30 – 50) cm, also sometimes present in the sediments and considered as crevasse splay(s) sediments.

– **Carbonate Subfacies (Subfacies 3c):** The sediments of this subfacies are light grey in colour and consist mainly of micrite; sometimes recrystallized into spary grains. Very few carbonate units not exceeding 1 m were locally observed, which interrupt the sediments of Subfacies 3b. Fresh water fauna such as ostracods and gastropods were identified in most of these units. Most probably, this subfacies represents shallow lake sediments in the flood plain subenvironment.

PETROGRAPHY

▪ Petrographic Study of Sands and Sandstones

Petrographic study of 28 samples of the Mukdadiya Formation was carried out and the results are presented in Table (1). The study revealed the presence of quartz, feldspar and rock fragments. The sandstones are cemented mainly by calcite with subordinate iron oxides, silica and gypsum. The sandstones are mainly classified as litharenite according to Folk's classification with subordinate feldspathic litharenite (Folk, 1974). The description of sandstone constituents is mentioned hereinafter.

Table 1: Average percentage of the constituents in the sandstones of Mukdadiya Formation in the studied area

Constituents	Percentages (%)
Quartz	30.6
Feldspar	5.7
Sedimentary rock fragments	29.0
Metamorphic rock fragments	3.7
Igneous rock fragments	1.7
Heavy minerals	2.4
Cement and Matrix	26.6

─ **Quartz:** The average percentages of the quartz grains is 30.6% and ranges from (17.7 – 42.5) %. The grains are mainly subrounded to subangular with subordinate angular to rounded grains. Most of the quartz grains are monocrystalline with small amount of polycrystalline. The monocrystalline grains form more than 90% of the identified grains. They are moderately sorted and range from (0.11 – 0.28) mm in size. Some of the grains show undulose extinction. Inclusions are common and the identified minerals are tourmaline and zircon, and also volatile bubbles (?). The polycrystalline grains are less in percentage and are coarser in grain size than the monocrystalline quartz grains.

─ **Feldspar:** The average feldspar content is 5.7% and ranges from (1 – 14) %. The grains range in size form (0.16 – 0.3) mm and they are mainly angular to subangular, however, subrounded grains were observed. Some of the grains are completely altered into clay and sericite, and only their outlines are preserved. Two types of feldspars are observed: Alkali feldspar and plagioclase. The alkali feldspar is represented by orthoclase and microcline. The orthoclase is recognized by cloudy relief, whereas the microcline by cross-hatch twining. The plagioclase feldspar is of albite twining; however, some of them has Carlsbad twining or a combination of Carlsbad and albite twining. Some of the grains are altered. The identified plagioclase minerals range from andesine to bytownite, based on the degree of maximum extinction angle of albite and Carlsbad twining.

─ **Rock Fragments:** The rock fragments are the highest recorded constituents in the studied sandstones. They are relatively coarser than any other components and range in size from (0.18 – 0.46) mm. The recognized rock fragments are sedimentary, igneous and metamorphic types. The sedimentary fragments are the predominant, their average percentages is 29.0% and consist of carbonate, chert, sandstone and argillaceous fragments. The metamorphic fragments are represented mainly by schist, slate and phyllite and their average percentages is 3.7%, whereas the identified igneous fragments are acidic igneous fragments (granite and pegmatite) andesite, rhyollite and basalt, and with average percentages of 1.7%.

– **Cement and Matrix:** The average content of the cement and matrix materials is 26.6%. Four types of cement are recognized; calcite, gypsum, iron oxide and silica. Most of the calcite cement is sparry calcite and some of them are micritic. The matrix is composed of clay and silt size grains of quartz, clay, mica and carbonate. The grains of matrix are randomly distributed between the minerals constituent of the rocks and form as binder to the detrital grains. It is thought in this study that most of the matrix is detrital in origin. However, some of them might be formed by disintegration and alteration of the rock fragments and unstable grains; such as feldspar and mica.

▪ **Petrographic Study of Mudstones and Claystones**

The studied fine grained sediments of Mukdadiya Formation are represented mainly by mudstone with few claystone units. The petrographic study of the mudstones and claystones revealed that they are composed of clay minerals, quartz and sometimes with subordinate micritic calcite. The identified clay minerals are montmorillonite, kaolinite, illite and chlorite, as they are described in detail in Clay Minerals paragraph. Petrographic terms are mudstones, sandy mudstones and claystones.

MINERALOGY

▪ **Heavy Minerals**

The heavy mineral assemblages of the sandstones of the Mukdadiya Formation revealed the presence of two groups: Opaque, and transparent minerals (Table 2). The following are the main characteristic features of each mineral.

Table 2: Average percentages of the heavy minerals in the studied sediments of Mukdadiya Formation

Heavy Minerals	Percentages (%)
Opaque	26.5
Epidote	45.4
Amphibole	4.2
Tremolite	T
Pyroxene	1.4
Garnet	9.8
Zircon	0.7
Rutile	0.5
Chlorite	1.3
Biotite	0.3
Unidentified	9.8

– **Opaque Minerals:** Opaque minerals were identified in all studied samples, but in different proportions. They are represented mainly by hematite and limonite. The shapes of the identified minerals are dominantly subrounded to subangular.

– **Transparent Minerals:** The identified species of the transparent minerals are epidote, amphibole, pyroxene, garnet, zircon, rutile, tourmaline, titanite, biotite, chlorite and barite – celestite. For the purpose of description, the identified transparent minerals are classified in this study into four groups: Epidote, amphibole, pyroxene and others, they are mentioned hereinafter.

Epidote Group: It is the most abundant group in the studied transparent heavy minerals, and consists mainly of epidote and clinozoisite. The epidote crystals vary in colour from colourless to pale green. They are mostly non-pleochroic and with parallel extinction. The minerals are highly altered and the clinozoisite are recognized as worn prism and moderate birefringence.

Amphibole Group: The amphibole group is represented mainly by hornblende with subordinate tremolite – actinolite and glaucophane in trace amount. The hornblende is green to brownish green in colour, weakly corroded and mostly elongated. Tremolite – actinolite, both are optically the same, therefore, can not be separated. They are colourless, elongated and with small extinction angle.

Pyroxene Group: The pyroxene group is dominated by clinopyroxene with subordinate orthopyroxene. The clinopyroxenes are mostly colourless and some of them are yellowish green in colour with no or weak pleochrism. The grains are mostly elongated some of them show inclusions and deeply to partially corroded. The orthopyroxenes are colourless with parallel extinction angle and weakly corroded.

─ **Other Minerals:** The other identified minerals are dominated by garnet, rutile, zircon and tourmaline with subordinate titanite, biotite and barite – celestite. The dominated identified minerals are described hereinafter.

Garnet: It is isotropic, mostly colourless, rarely brownish, pinkish and yellowish in colour. Most of the crystals are angular, with subordinate subrounded and subangular crystals, with opaque and unidentified mineral inclusions.

Rutile: Rutile is red and orange in colour, high in relief and subrounded to rounded crystals.

Zircon: It is rare and not observed in most of the samples. Zircon is mostly colourless with subordinate pinkish grains. It is mostly angular to subrounded, however, very few rounded and euhedral to subhedral grains were observed.

Chlorite: Chlorite is mostly green in colour and varies from rounded to subangular and some grains showing fractures. Inclusion of opaque black minerals are present in some grains.

▪ **Clay Minerals**

In the studied samples, the following types of clay minerals were identified: Montmorillonite, chlorite, illite and kaolinite (Table 3). They are described hereinafter.

─ **Montmorillonite:** Montmorillonite is identified in few samples, it varies from (8 – 28) % (Tables 3). However, combined phases of montmorillonite and chlorite were recognized. These minerals were measured as one value, because it is difficult to measure these two phases separately. The occurrence of montmorillonite in the flood plain sediments might suggest a detrital origin for the sediments. The mineral is transported with other detrital minerals and laid down in fluviatile environment. The missing of montmorillonite in some samples might reflect variation in the source area. Awad (2010) considered the montmorillonite mineral in the marine Balambo Formation in northern Iraq as of detrital origin.

Table 3: Percentages of clay minerals in the studied sediments
of the Mukdadiya Formation

No.	Sample No.	Mont.	Chl.	Ch. + Mont.	Ill.	Ka.	Total	Depth (m)	Name
		(%)							
1	ABH$_{1/2}$	28			5	3	36	44.0 – 44.3	Mudstone
2	ABH$_{1/3}$			33	11		44	70.0 – 70.2	Claystone
3	ABH$_{1/4}$			3	< 1	<1	3	95.0 – 95.4	♀Sandstone
4	ABH$_{1/5}$		31		7	2	40	115.3 – 115.5	Claystone
5	ABH$_{2/1}$	20	14		9	Trace	43	44.2 – 44.4	Claystone
6	ABH$_{2/2}$			31	10		41	70.0 – 70.7	Claystone
7	ABH$_{2/3}$			7	2	2	11	95.1 – 95.3	♀Sandstone
8	ABH$_{2/4}$		27	15		2	44	115.4 – 115.6	Claystone
9	ABH$_{2/5}$			34	6		40	141.8 – 142.0	Claystone
10	ABH$_{3/1}$			33	16	5	54	165.0 – 165.2	Claystone
11	ABH$_{3/2}$	8			2	1	11	51.1 – 51.3	Claystone
12	ABH$_{3/2}$		35		12		47	75.1 – 75.3	♀Sandstone
13	ABH$_{3/4}$	Trace			5		5	102.0 – 102.2	Claystone

(Mont. = Montmorilinite, Chl. = Chlorite, Ill = Illite, Ka. = Kaolinite)

– **Chlorite:** Chlorite is identified in some samples and it varies from (14 – 35) %. The presence of chlorite mineral in the sandstones and claystones and its occurrence in most samples, suggested a detrital origin for this mineral. The study of heavy minerals revealed that sandstones are composed of pyroxene, amphibole and biotite minerals. Therefore, part of the recognized chlorite mineral might be was produced diagenetically from other minerals.

– **Illite:** Because it is difficult to estimate semiquantitativelly the percentages of palygorskite, therefore, illite is combined with palygorskite in most of the studied samples. The illite is totally missing in some of gypcrete samples in the Quaternary sediments (Basi and Karim, 1990) and the palygorskite is identified and estimated alone in the gypcrete samples and is considered to be formed diagenetically as it is connected with secondary evaporate minerals (condition of high Mg necessary for the formation of palygorskite). Because palygorskite was not identified alone in the studied samples, as in the sediments associated with gypcrete of the Quaternary sediments and the missing of evaporate minerals in the sediments, therefore it is suggested that the presence of illite alone in the studied samples in which the illite is combined with palygorskite as one phase. Illite can be formed in alkaline marine environment (Potter *et al.*, 1980) and could be formed by weathering and erosion of igneous and metamorphic rocks rich in mica. The presence of illite in sandstones and claystones and the fluviatile nature of these sediments (Basi, 2007) suggest a detrital origin for the illite.

– **Kaolinite:** Kaolinite mineral is present in most of the studied samples in various proportions, it ranges from (1 – 5) %. The kaolinite is present in sandstones and claystones. The common occurrence of kaolinite in most of the studied samples (in the claystones and sandstones) suggests a detrital origin. Kaolinite is formed in continental weathering and from weathering of acidic igneous rocks in moist climate. The absence of kaolinite in some samples and the usual low amount is most probably related to low amount of acidic igneous rocks, in the source area and to the arid climate. The low amount of acidic igneous rocks and the arid climate are confirmed from the petrographical and heavy mineral studies of the sediments of the Mukdadiya Formation.

DISCUSSION AND CONCLUSIONS

The Mukdadiya Formation represents typical meandering sediments, which were deposited by rapid erosion and uplifted mountains in the north and northeast of Iraq, deposited in troughs suffering continuous subsidence in their basin. The sediments are represented by several fining-upward cycles in which three facies were recognized, these are: The sandstone facies, which most probably represents channel deposits, the gravelly sandstone and conglomerate facies, which represents climatic changes or tectonic activity in the source area, and fine grained sediments facies, which represents over bank sediments.

Petrographic study of sandstones of Mukdadiya Formation reveals that they are immature, poorly sorted and mostly clayey. They are composed essentially of quartz, followed by sedimentary rock fragments (mainly carbonate and argillaceous grains), then by feldspar and followed by metamorphic and igneous rock fragments. The sandstone components are cemented essentially by carbonate, then followed by iron oxides. The sandstones are classified as litharenite. The immaturity and composition of the sandstones require rapid erosion promoted by high relief or aridity, because feldspar and rock fragments are stable in such conditions. The source area, based on the petrographic study indicates the presence of sedimentary rocks; as the main source with subordinate metamorphic and igneous rocks.

The identified heavy minerals, in the studied samples are: Opaque minerals, epidote, pyroxene, amphibole, garnet, zircon, rutile, tourmaline, titanite, biotite and barite – celestite. The heavy mineral assemblages indicate a combination of metamorphic rocks and intermediate to basic igneous rocks, with minor contribution from acidic igneous rocks as a source area. However, large contribution from sedimentary rocks (mainly carbonate) based on petrographic and heavy minerals studies were suggested.

The distribution of heavy minerals revealed that there is no uniformity in the distribution of any species of the minerals, vertically in the studied sediments. The non-uniformity in the distribution of these minerals might be related to the random fluctuation in the streams carrying the sediments, grain size, local variation in the source area, and the degree of erosion, and to lesser extent diagenesis. However, variation in the source area and grain size seems to be more likely.

The identified clay minerals are: Montmorillonite, chlorite, illite and kaolinite. The genesis of montmorillonite, illite and kaolinite, is detrital, whereas the chlorite is also mainly detrital and partly diagenetic by alteration of pyroxene, amphibole and biotite minerals. The low amount of kaolinite indicates the minority of acidic igneous rocks; in the source area and dominated arid climate in the source area also. No specific vertical trend of the clay minerals was observed in the studied sediments. However, the variation in the percentages of montmorillonite, chlorite, kaolinite and illite might be related to the variations in the source area.

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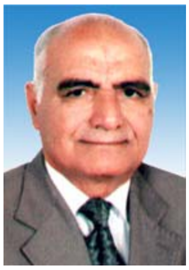
About the author



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